Next to leading order predictions for $\pi_0\gamma$ and $\pi_0\pi_0$ production at the LHC

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The precise knowledge of photon pair production rates at the LHC is crucial to estimate the sensitivity to a Higgs boson in the intermediate mass range. This background consists not only of prompt photons but also of fake photons stemming from pion decay. We present next to leading order predictions for the invariant mass distributions of pion photon and pion pairs.

1   Introduction

The results from the LEP experiments suggest that the mass of the Higgs boson should lay in a relatively narrow window. The lower bound from direct searches at LEP and the 95% c.l. indirect upper bound is [1]

$$113.5 \text{ GeV } \leq M_{Higgs} \leq 212 \text{ GeV}. \tag{1}$$

The upper bound stems from the sensitivity of precision observables to quantum corrections which increase with the Higgs mass. This means that the discovery of the Standard Model Higgs boson is to be expected in the near future, though one has to say that the validity of the upper bound depends on the assumption that the Higgs sector is genuinely perturbative [a]

For the LHC the Higgs mass window (1) means that the decay into photon pairs will be a prominent search channel, namely in the range 100 GeV $\leq M_{Higgs} \leq$ 140 GeV. If one wants to study the signal significance it is thus mandatory to know the di–photon background as precisely as possible.

2   Photon pair production mechanisms at the LHC

Apart from the Higgs decay into two photons which has a cross section of around 50 fb^{-1} there are much more important production mechanism for di–photon events. Although the study of

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[a]A strongly interacting electroweak symmetry breaking sector is not ruled out yet. Non-perturbative corrections which are not reliably calculable with existing techniques may fake the presence of a light Higgs boson.

photon final states is itself interesting I will call them "background" throughout this article. One can mainly distinguish three classes:

Direct Photons: Both photons are produced in a hard interaction.

Photons from fragmentation: One or both photons are produced in the hadronisation of a QCD parton.

Meson decay: Produced mesons decay into photon pairs which are misidentified as one single photon in the detector.

The first two mechanisms are irreducible backgrounds in the sense that the two photons there can be produced with the same kinematics as in a Higgs boson decay. Still, the fact that in the second case at least one photon is accompanied with some amount of hadronic energy allows to suppress this component to a large extent. A theoretical next to leading order study for the irreducible part of the di–photon background can be found in [2]. There the Fortran code DIPHOX was used to compute physical observables using next to leading order matrix elements for all types of contributions. The same code can be used to compute the background due to meson decay by replacing the photon fragmentation functions by pion fragmentation functions or other meson fragmentation functions.

The discrimination of photons coming from fragmentation and pions is possible because in both cases the electromagnetic signal will be accompanied with some hadronic energy. One can now impose isolation criteria by not allowing more than a certain amount of hadronic energy, E_{Tmax}, in a cone, $R = \sqrt{(\Delta\phi)^2 + (\Delta y)^2}$ defined in rapidity and azimuthal space around the photon/meson direction.

3 Next to leading order predictions for $\pi_0\gamma$ and $\pi_0\pi_0$

We now present next to leading order predictions for pion pair and pion photon production at the LHC. The remaining uncertainties for these predictions are three–fold. First there are theoretical uncertainties due to missing higher order corrections. They are typically estimated by varying unphysical scales present in the calculation around some value chosen for the hard scale. In our case one has a dependence on the renormalisation scale, μ, the factorisation scale, M, and the fragmentation scale, M_f. A detailed analysis of scale dependencies will be presented elsewhere [5]. A second uncertainty comes from the fragmentation functions used. Typically they are parametrised by data samples in the intermediate z range where z is the energy fraction of meson to parent parton. A recent parametrisation [3] was used for the plots below. Imposing severe isolation criteria to suppress background photons and mesons from fragmentation imposes a lower bound on this variable, namely

$$z > z_{min} = \frac{p_{Tmin}}{p_{Tmin} + E_{Tmax}}. \tag{2}$$

Here p_{Tmin} is the lower experimental cut–off for the transverse momentum of the observed boson, typically 25 GeV at the LHC. Obviously severe isolation criteria as e.g. $E_{Tmax} = 5$ GeV in a cone $R = 0.4$ restrict the z range to values near 1 where the fragmentation functions are poorly known. This induces a third uncertainty on the theoretical side. One has to be aware that potentially large logarithms $\sim \log(1-z)$ enter the game which may have to be resummed to give a reliable prediction. All these issues deserve further investigation [5].

In the plots presented below we have chosen $\mu = M = M_f = M_{bb}/2$, where M_{bb} is the invariant mass of the produced boson pair, $b = \gamma, \pi_0$. We used the MRST2 [4] structure functions. Fig. 1 shows the invariant mass distribution of $\gamma\gamma$, $\gamma\pi_0$, $\pi_0\pi_0$ for a very loose isolation criteria, $E_{Tmax} = 100$ GeV in a cone of $R = 0.4$. In addition to the isolation cuts, standard rapidity and
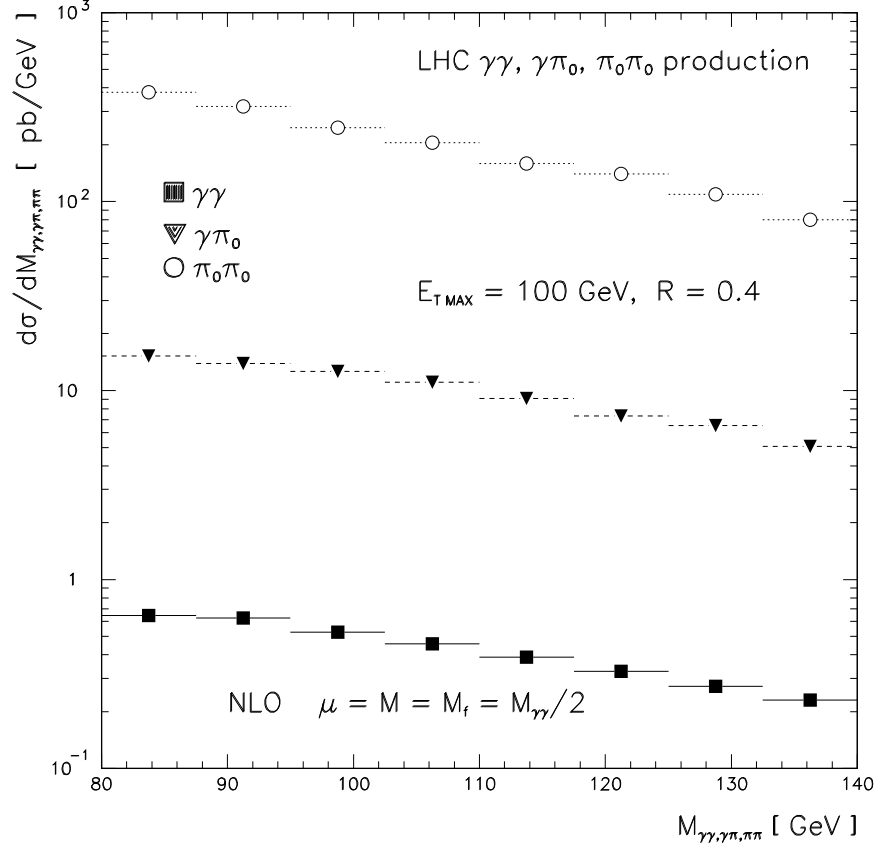
Figure 1: Production rates of $\gamma\gamma$, $\gamma\pi_0$, and $\pi_0\pi_0$ at NLO with isolation cut: $E_{Tmax} = 100$ GeV in cone $R = 0.4$.

p_T cuts were applied: $|y(boson_{1,2})| < 2.5$, $p_T(boson_1) > 40$ GeV, and $p_T(boson_2) > 25$ GeV. Fig. 1 gives an idea of the large suppression factors which are needed for the reducible backgrounds to find a Higgs signal in the given mass window. Though being a reducible background the huge production rates for pions make a reliable understanding of these rates necessary.

In Fig. (2) the dependence on isolation criteria for $\pi_0\gamma$ (left) and $\pi_0\pi_0$ production (right) is shown. Again, in addition to the isolation cuts, standard cuts on the observed bosons as defined above are applied. With an isolation criteria of $E_{Tmax} = 15$ GeV in a cone $R = 0.4$ the rates for $\gamma\gamma$, $\gamma\pi_0$, $\pi_0\pi_0$ are all still of order pb/GeV. Increasing the cut (lowering E_{Tmax}) does not change the $\gamma\gamma$ background much from now on, as dominantly direct photons are present already which are insensitive to the cut. On the other hand the pion rates are further reduced. Whereas the differential cross section $d\sigma/dM_{\pi\pi}$ for $\pi_0\pi_0$ is of the order fb/GeV for a isolation criteria of $E_{Tmax} = 5$ GeV, the differential cross section for $d\sigma/dM_{\pi\gamma}$ is still 1 to 2 orders of magnitude higher and because of the uncertainties mentioned above still a dangerous background. One should always bare in mind that the Higgs signal will only be around 50 fb^{-1}/GeV, if one assumes that the signal is located inside a 1 GeV bin. It should be said that experimentally further reduction factors for fake photons coming from meson decays can be applied. These are typically of order 2 for any misidentified pion [6]. We note that the next to leading order corrections are typically 50%–100% of the leading order contribution but general quantitative statements of their sizes may be dangerous in connection with isolation criteria. This will be discussed elsewhere [5].
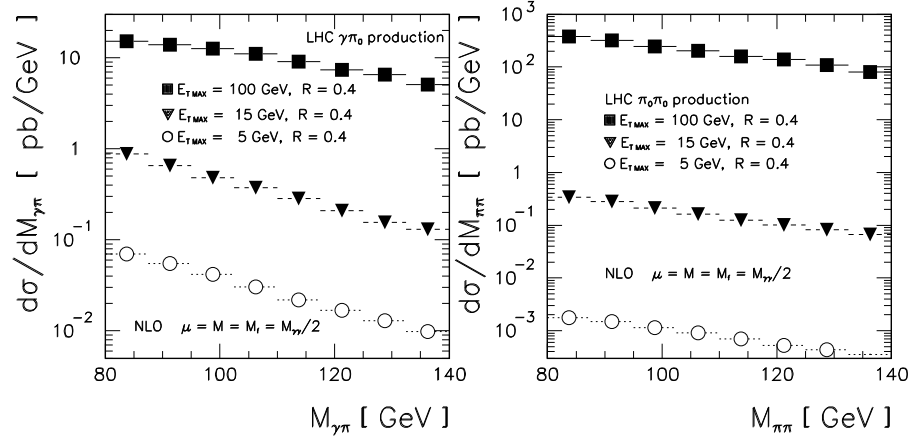
Figure 2: Effect of isolation on the $\gamma\pi_0$ (left), $\pi_0\pi_0$ (right) invariant mass distribution.

4   Conclusion

Next to leading order results for pion photon and pion pion production at LHC are presented. The present calculation pins down theoretical uncertainties for the production rates of these processes. This is important, as they are huge backgrounds for Higgs searches in the di–photon channel. Isolation criteria suppress pion pair production considerably but the pion photon channel remains still relevant. We remarked that for stringent isolation cuts the knowledge of the pion fragmentation functions at the high z end is mandatory and also that — on the theoretical side — resummation of $\log(1-z)$ terms could become important.

References

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